The Effects of Impedance on Harmonic Distortion

The magnitude of harmonic current distortion, for six pulse rectifiers such as those used in variable frequency drives (VFD) and uninterruptible power supplies (UPS), depends greatly on the upstream effective impedance, namely the series inductive reactance between source and load. The upstream impedance can include the generator, transformer, circuit conductors, line reactor and DC link choke. Although it is not a linear relationship, generally speaking, the more impedance, the lower the harmonic current distortion, until reaching the point of diminishing return at about 10% total impedance.

The typical harmonic current distortion for any six pulse rectifier type load, can be predicted based on the effective impedance. Contrary to transformer and reactor nameplate impedance, the basis of rating for effective impedance is the actual circuit fundamental current and system voltage. For more information on effective impedance, see Tech Note # TN-GENL-1.

Effective Impedance	0.5%	1.0%	3%	5%
Current Distortion	100% THD-I	72% THD-I	44% THD-I	35% THD-I

Since the nameplate impedance rating of a transformer and reactor is based on its full load rating, whenever the load current is less than transformer or reactor FLA, the effective percent impedance will be lower than the nameplate impedance. This means that harmonic current distortion, as a percentage of fundamental current, will be lowest when the load current is nearest to the maximum rating of the transformer or line reactor. A 5% impedance line reactor, will only act like a 3% line reactor when the load current is 60% of the line reactor's full load current rating.

Example: 30kVA, 480 volt VFD is supplied from a 5% impedance transformer rated 50kVA.
When the VFD operates at full load, the effective percent impedance offered by the transformer is
Effective Impedance = 5% x (30kVA / 50kVA) = 3% effective impedance and will experience about 44% THD-I.
Even though the transformer has a nameplate impedance rating of 5%, the best performance that can be achieved in this scenario is similar to a transformer with a nameplate impedance of 3%.

If a line reactance of 2% is added, then at full load conditions, the effective percent impedance will be 5%, and the harmonic current distortion will be about 35% THD-I.

Transformer nameplate impedance cannot be considered as the effective impedance because normally the transformer capacity is considerably larger than the load. In many cases, the transformer supplies several pieces of equipment and in those cases, its kVA rating may be several times larger than any individual load, rendering the transformer impedance ineffective at reducing harmonic current distortion. On the other hand, line reactors are typically selected based on an individual load rating and with the reactor current rating near the FLA rating of the equipment connected as a load.

The typical harmonic current distortion associated with various effective percent impedance ratings are indicated in the following chart.

Zeff	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%
% THD-I	100%	72%	60%	52%	47%	44%	41%	39%	37%	35%

Zeff	5.5%	6.0%	6.5%	7.0%	7.5%	8.0%	8.5%	9.0%	9.5%	10.0%
% THD-I	33.8%	32.5%	31.5	30.5%	30	29%	28	27.5%	27	26.5%

It is important to recognize that the effective impedance is also an indication of the full load voltage drop across this series reactance. One should avoid excessive voltage drop. It is possible however to achieve a high effective impedance, without a severe AC voltage drop when line reactance is combined with dc bus reactance. For example, 1% effective transformer impedance + 5% line reactance + 3% dc bus reactance = 9% total effective percent impedance, and the estimated harmonic distortion is 27.5% at full load.